

NAFEC TECHNICAL LETTER REPORT

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FLAME PROPAGATION THROUGH
SPRAYS OF
ANTIMISTING FUELS

by

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PREFACE

This evaluation was conducted as part of the Aircraft Systems Fire Safety Program, NPD No. 18-471, sponsored by ARD-520, Mr. Richard A. Kirsch. The project number is 181-520-130 and the NAFEC Program Manager is Mr. Constantine P. Sarkos. Further information can be obtained from Thor, I. Eklund, ANA-420, (609) 641-8200, extension 2322.

ABSTRACT

Schlieren movies were taken of flame propagation through sprays of jet fuel and antimisting jet fuels. The fuel was pumped through a 1/4-inch stainless steel tube running concentric with a 1-inch air supply pipe. The air atomized the fuel, and the mixture was passed through a diffuser to an oxy-acetylene torch. Air velocities and fuel flow rates were varied to affect fuel particle size and thereby control the flammability of the sprays. The motion pictures demonstrate the contrast in flammability between neat jet fuel and modified fuels.

CONCLUSIONS

The following points can be stated as a result of a comparative evaluation of the motion picture schlieren films:

1. The flame propagation through coarse sprays does not proceed by a simple diffusion flame front.
2. Antimisting kerosene (AMK) sprays are not flammable in many cases where a Jet A spray is flammable.
3. Given high enough airspeed and fuel delivery rate, AMK sustains flame propagation.

RECOMMENDATIONS

Additional efforts are needed to quantify the particle population statistics and to correlate these small-scale atomization results with larger scale tests. As AMK additives become more readily available, there will be more large-scale and small-scale data available for correlation. However, describing the particle population represents a challenging problem, particularly in the case of the nonspherical AMK particles.

INTRODUCTION

PURPOSE

The purpose of these investigations was to develop further understanding of flame spread phenomena through sprays of antimisting fuels. Increased knowledge of this behavior is necessary background to provide adequate technical support for both small scale and full scale antimisting fuel fire tests.

BACKGROUND

For well over a decade, the Federal Aviation Administration (FAA) has encouraged the development of fuel additives that might prevent fuel fires during an aircraft crash. During a crash, fuel can be dumped from broken wing tanks at a rapid rate due to the deceleration forces. While the aircraft continues to move, the escaping fuel is exposed to high airspeeds which result in the atomization of the kerosene. While Jet A is not flammable in bulk form unless heated to its flashpoint, Jet A becomes as hazardous as Jet B or gasoline when atomized. Hence, the FAA efforts have been primarily aimed at finding additives that could minimize the spray-forming capability of the fuel, while having minimal effects on existing aircraft fuel system.

Until 1971, efforts were primarily aimed at gels and emulsions. However, these modified fuels generated insurmountable problems in the fuel system. Activity since 1971 has primarily centered around the antimisting fuels (AMK).

These fuels consist of a Jet A solvent and a high-molecular weight polymeric solute. The polymer may have a molecular weight in excess of 1 million, and concentrations as low as 0.2 percent have been shown to be effective. At the National Aviation Facilities Experimental Center (NAFEC) in Atlantic City, New Jersey, these antimisting fuels have been subjected to a variety of fire tests including air gun and catapult jettison, flame spread rates on liquid fuels, and fuel dumps from a wing section placed in a steady airflow.

Because none of the spray fire tests were suitable for reproduction at other laboratories due to size and cost, the FAA's Systems Research and Development Service directed NAFEC to develop a small-scale test that was inexpensive to fabricate and could be employed as a standard test for the antimisting fuels. The resulting is shown in figure 1 and described in reference 1.

DISCUSSION

TEST APPARATUS

In order to develop the atomization technique employed in this test, a Fuel Spray Photographic Chamber was developed as shown in figure 2 and described in reference 2. Larger scale tests described in reference 3 have shown that certain antimisting fuels form characteristic nonspherical drops or strands when atomized by an airstream. Any small-scale atomization technique would have to form similar droplet geometries. Figures 3, 4, and 5 show droplet formation in the Spray Chamber from Jet A, AM-1, and FM-9 fuels, respectively.

The atomization technique consists of a 1-inch air supply pipe followed by a diffuser cone. Fuel is injected into the pipe just upstream of the diffuser. Upon exit from the diffuser, the spray is exposed to a continuous oxy-acetylene ignition source. The atomization configuration is shown in figure 6. The Spray Chamber includes a provision for secondary airflow and a slight positive pressurization. This prevents spray buildup from recirculation within the chamber and shrouds optical and photographic components from particle impaction. A schematic of the chamber is shown in figure 7.

As a side effort to the small-scale test development, some efforts were made to elucidate flame propagation through these AMK sprays. In addition to the microphotographic system used to obtain the spark photographs shown in figures 3, 4, and 5, a schlieren system was developed for motion picture studies and shown in figure 8. Initially, the intent was to use the schlieren system to define flame fronts and thereby develop comparative flame speeds between Jet A and the AMK samples. As the movies demonstrate, no such flame fronts are visible. Rather, the drops seem to burn in clusters and flame propagation appears to proceed by some sort of entrainment mechanism.

The schlieren unit is a two-element system consisting of a primary mirror located one focal length from a horizontal adjustable slit .010 by .080 inch which provides the entrance cone. The beam is then reflected through the areas to be sampled to the schlieren head which in turn beams the field to the knife edge.

The light source used to date is a General Radio Strobolume which utilizes an oscillator control unit with external and internal modes of operation. This permits the unit to be operated from 30 to 40,000 flashes per minute, with flash durations of 15 microseconds (μ s), 12 μ s, and 10 μ s.

The cameras are mounted behind the knife edge at the same angle to the schlieren head as the angle formed between the primary mirror axis and the slit, and on the opposite side of the field. The supporting structure is designed so that the light source is below the schlieren field and the camera is above it at the same angle as previously mentioned, allowing a sampling area of 6 inch diameter.

DATA FILMS

Figures 9a, 9b, 9c, and 9d show color schlieren movie frames of Jet A, FM-9, FM-4, and AM-1 taken at 24 frames per second. Figure 9e, 9f, 9g, and 9h show the same order but at higher airflows and fuel flows. These pictures clearly show the peculiar geometrics resulting from the atomization as well as the effect of higher airspeeds on reducing the particle sizes. Also, the torch wake is quite visible in many of the frames. The round border on the projection screen is equivalent to the 6 inch diameter of the schlieren mirrors. In these and subsequent tests, the additive weight concentrations were FM-9 (0.3 percent), FM-4 (0.4 percent), and AM-1 (0.2 percent).

Figure 10a, 10b, 11a, and 11b are taken from four sequences of Jet A under different conditions. These are color schlieren sequences at 400 frames per second. The first of these four sequences was taken at relatively low air and fuel flow rates, and the droplets are quite distinct. The flame is confined to the region of the torch wake. In some of the frames of figure 10a, blue regions are evident in the wake. Usually, the next frame will show the blue region to have turned yellow. Apparently, the hot wake gases are able to evaporate enough vapor from the drops to form a fuel-air mixture slightly richer than the lean limit. A lean blue flame then passes through this mixture. This reaction generates enough additional heat to initiate the yellow diffusive burning of the drops seen in the next movie frame. In the second of the four sequences as represented by figure 10b, the same fuel-flow rate is subjected to higher air velocities. The fire is no longer confined to the torch wake, and the fuel particles are no longer distinct. In addition, there is no longer a distinct blue flame phenomenon. The last two of the four sequences are run at an intermediate airflow to the first and second sequences. However, the fuel flow in sequence three as shown in figure 11a is the same as in sequences one and two and is raised considerably in the fourth sequence as shown in figure 11b. One can observe a vortex-type flame propagation at the upper edge of the flow field, and this indicates an entrainment mechanism for flame propagation. In some of the frames, individual drop flames appear to coalesce into a larger flame which then moves along with the overall gas flow.

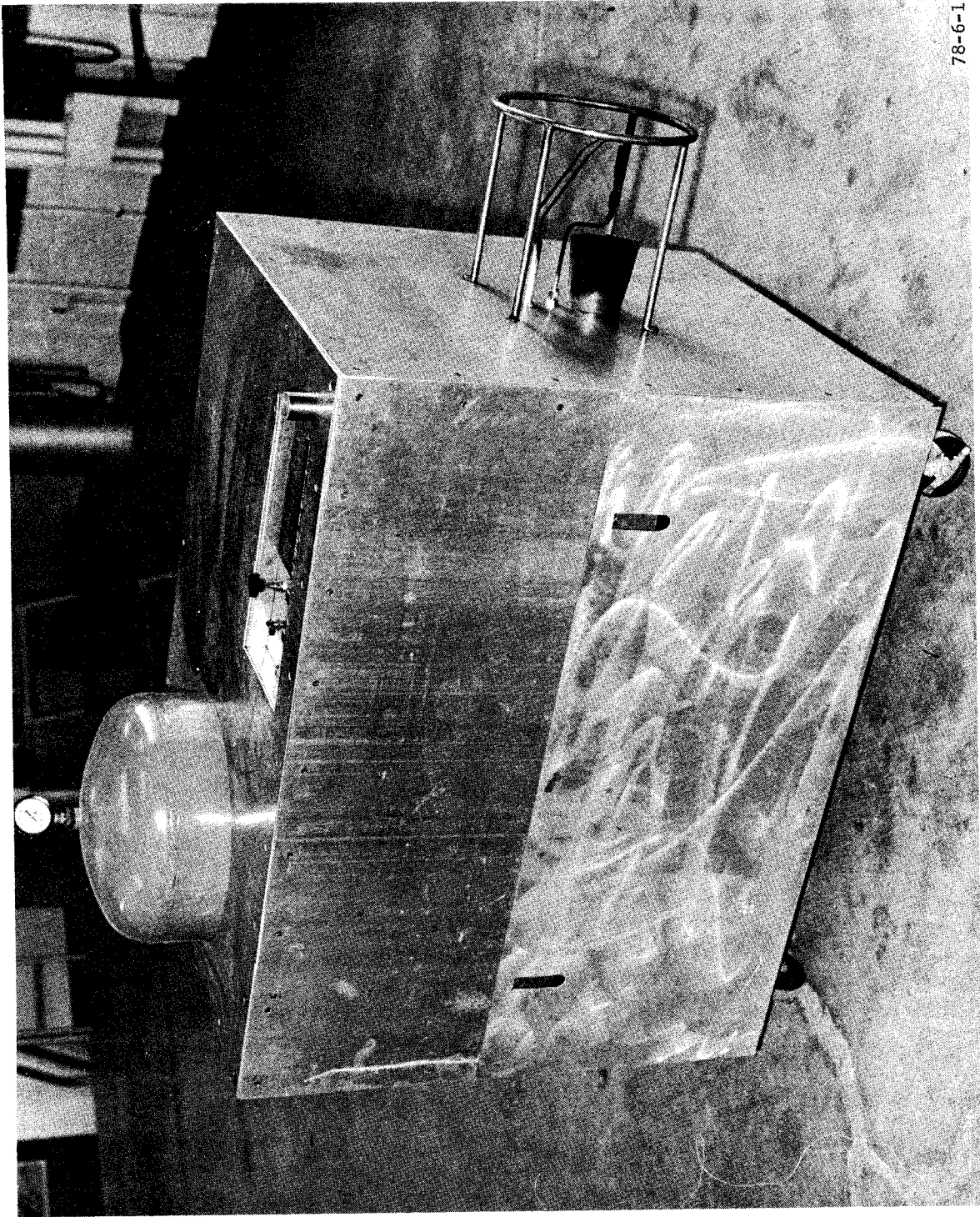
Figure 12 is representative of the third set of sequences. These are black and white schlieren movies taken of FM-9 at 400 frames per second. What is apparent is that increased fuel and airflows do cause the FM-9 to become more susceptible to flame propagation. The first and second of these three sequences (figures 12a and 12b) have the same airflow, but the fuel flow is increased from one to the next. In the third sequence (figure 12c), the fuel flow is the same as in the second sequence and the airflow is also increased. In a number of frames in this series, a schlieren bubble is visible just to the left of the flame pocket. This indicates that the burning droplets move as a group through the gas, and combustion products escape from the group. In flame front propagation, the flame front would precede any hot combustion gases.

The last two sequences were taken of Jet A and FM-9 run at identical flow rates. In this case their flammability properties are dramatically different. The Jet A burns, as shown in figure 13a, and the FM-9 shown in figure 13b shows no flame propagation from the torch. The actual parameters involved in these two tests are shown in table 1.

From these photographic studies, some general observations can be stated. First, there is some characteristic time scale involved. At 24 frames per second, the movies show continuous fire. At 200 to 400 frames per second, the movies show discrete fire pockets. At 1,000 frames per second, the fire pockets show no further definition. The following observations in the FM-9 tests indicate an entrainment mode of flame propagation:

1. Vortex flame spreading around gas stream edges.
2. Penetration of burning drop groups through the gas.
3. Burnout of flame pockets without further propagation.

The wake of the oxy-acetylene torch plays a significant role in the ignitability of the fuel sprays tested. The blue flame phenomenon noted in the Jet A test occurred exclusively in the torch wake. The AMK fuels will often burn in the wake without further penetration into the unheated spray outside the wake.



78-6-1

FIGURE 1. MODIFIED FUEL TEST APPARATUS

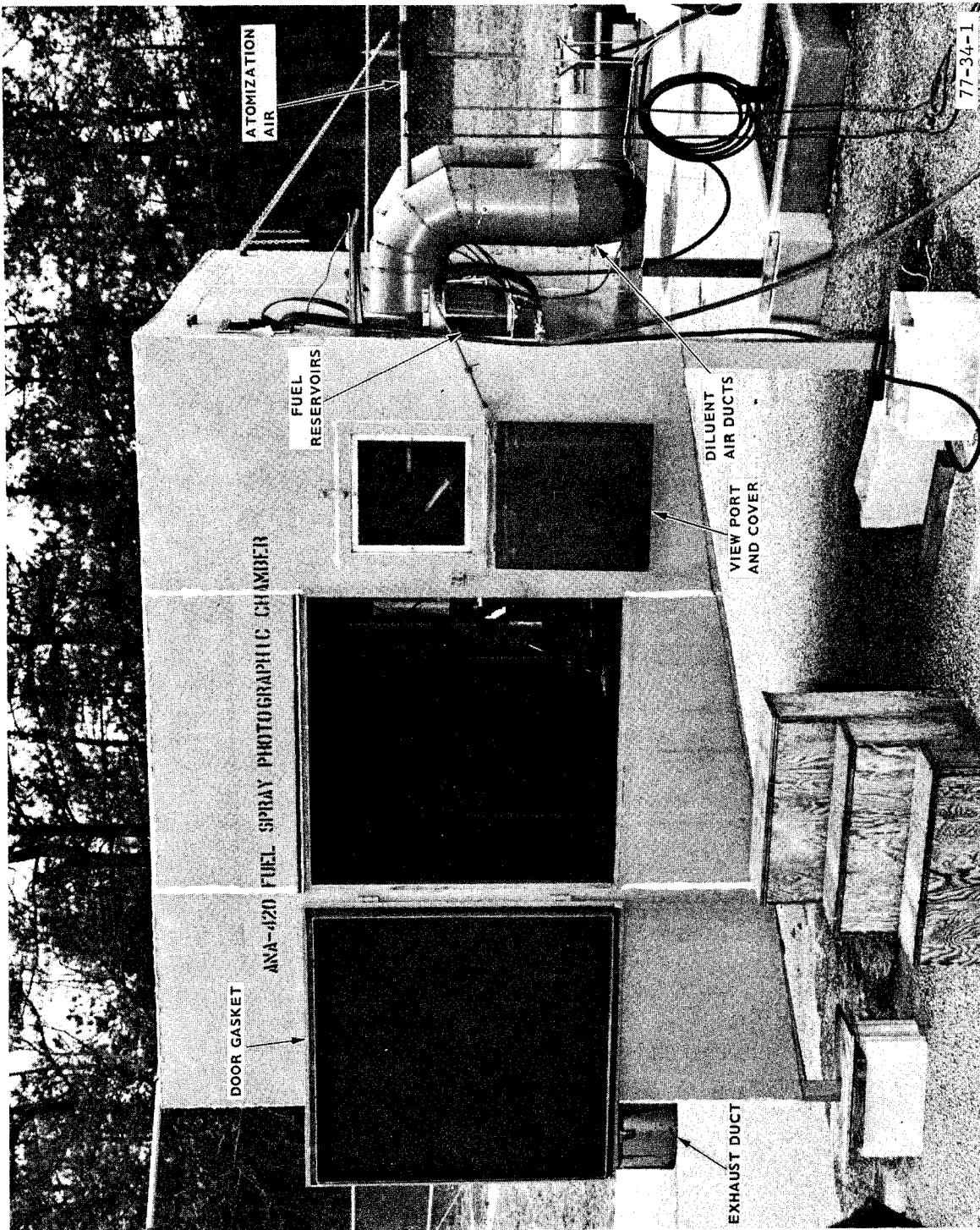
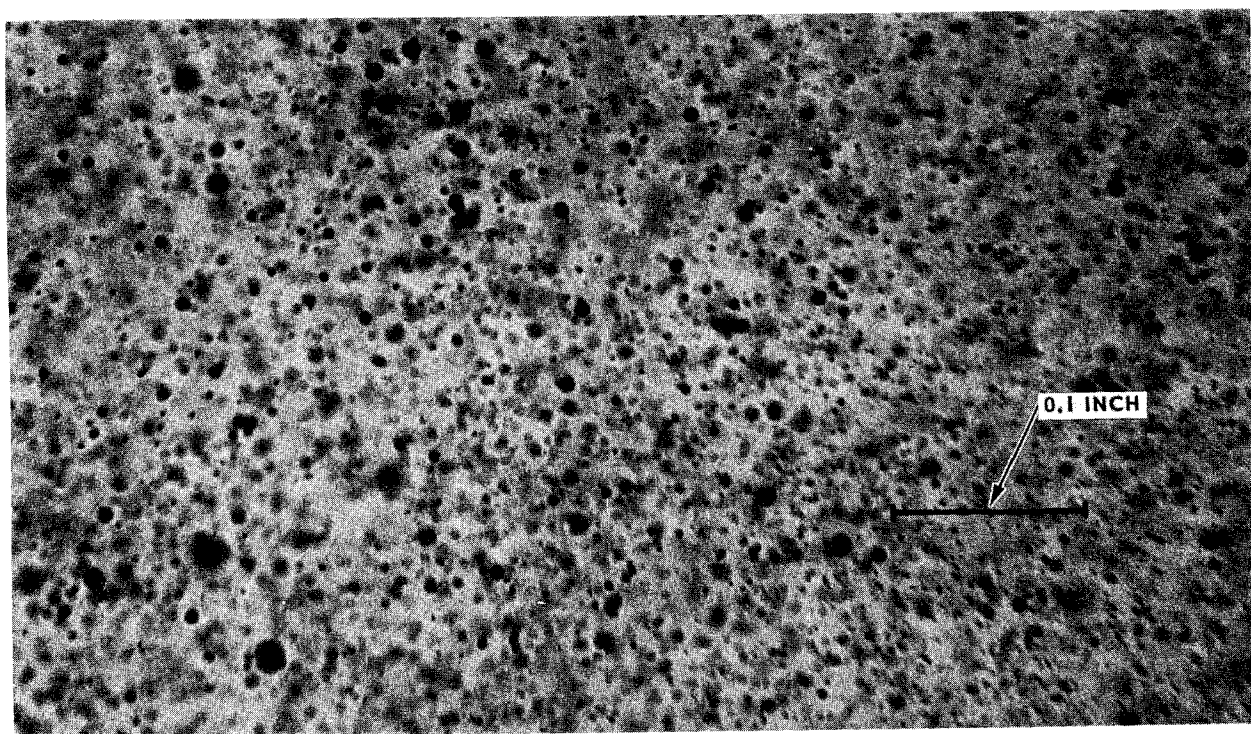
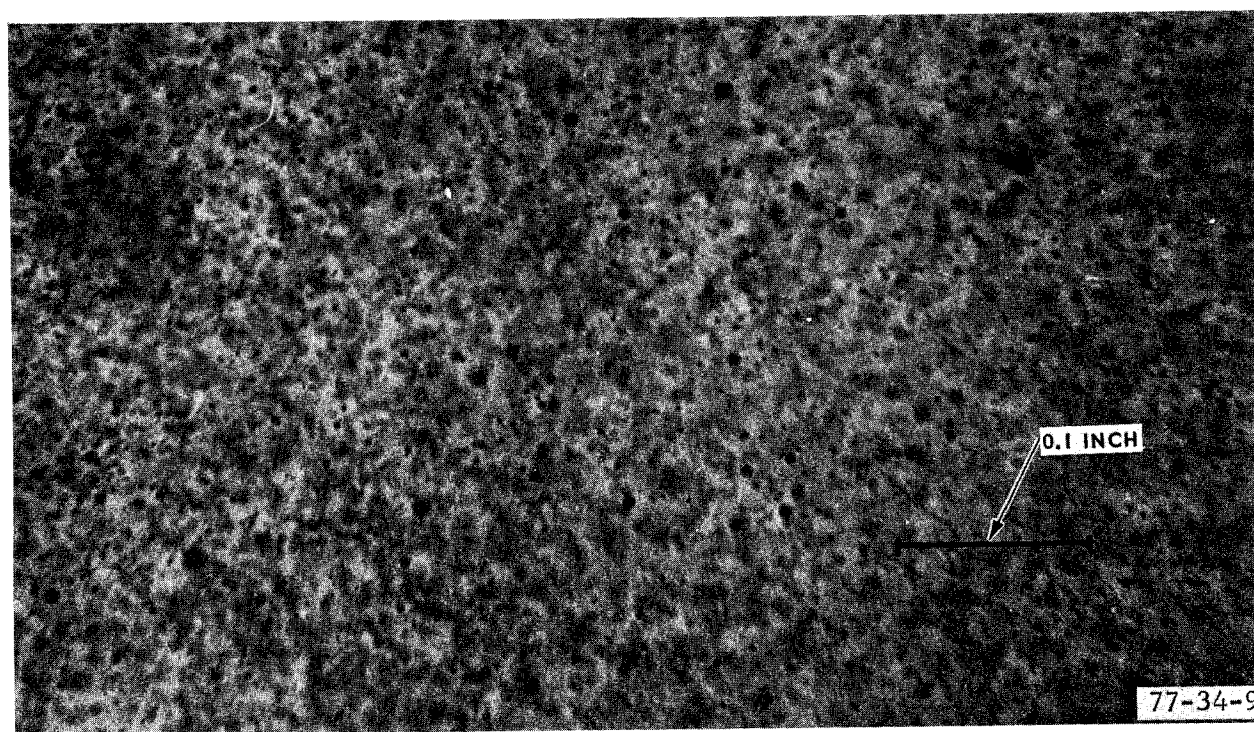


FIGURE 2. FUEL SPRAY PHOTOGRAPHIC CHAMBER

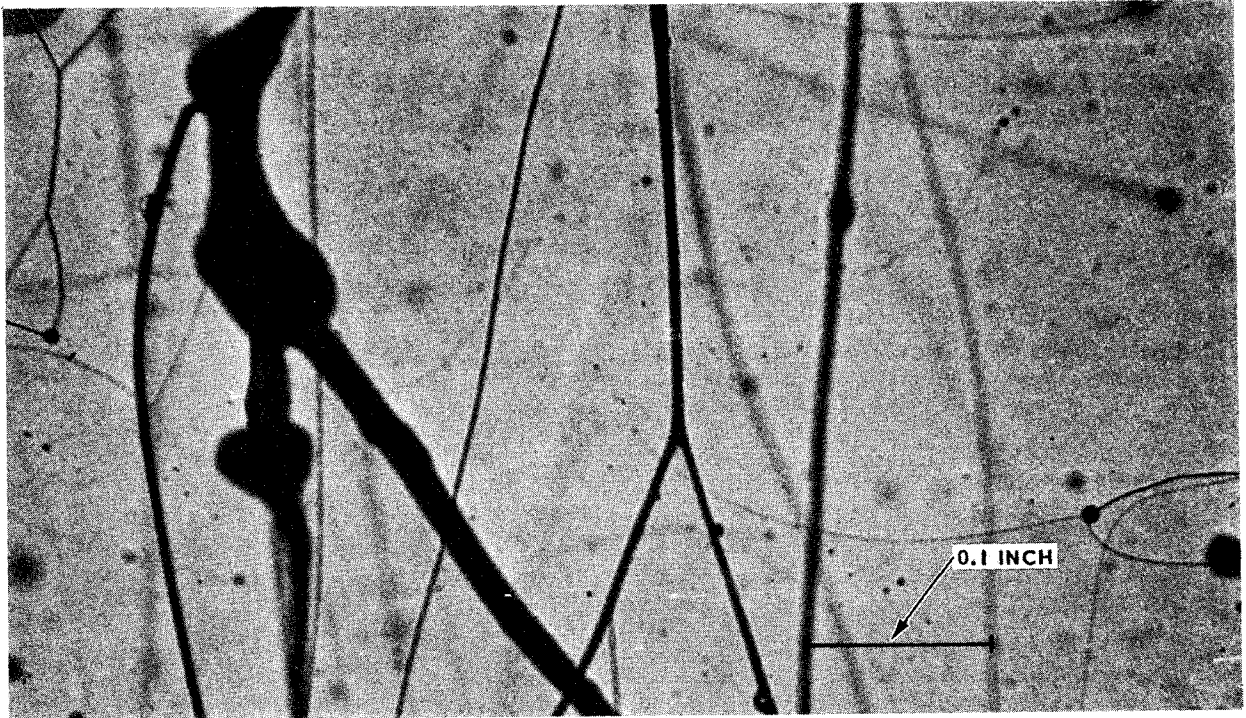


a. 200 mph

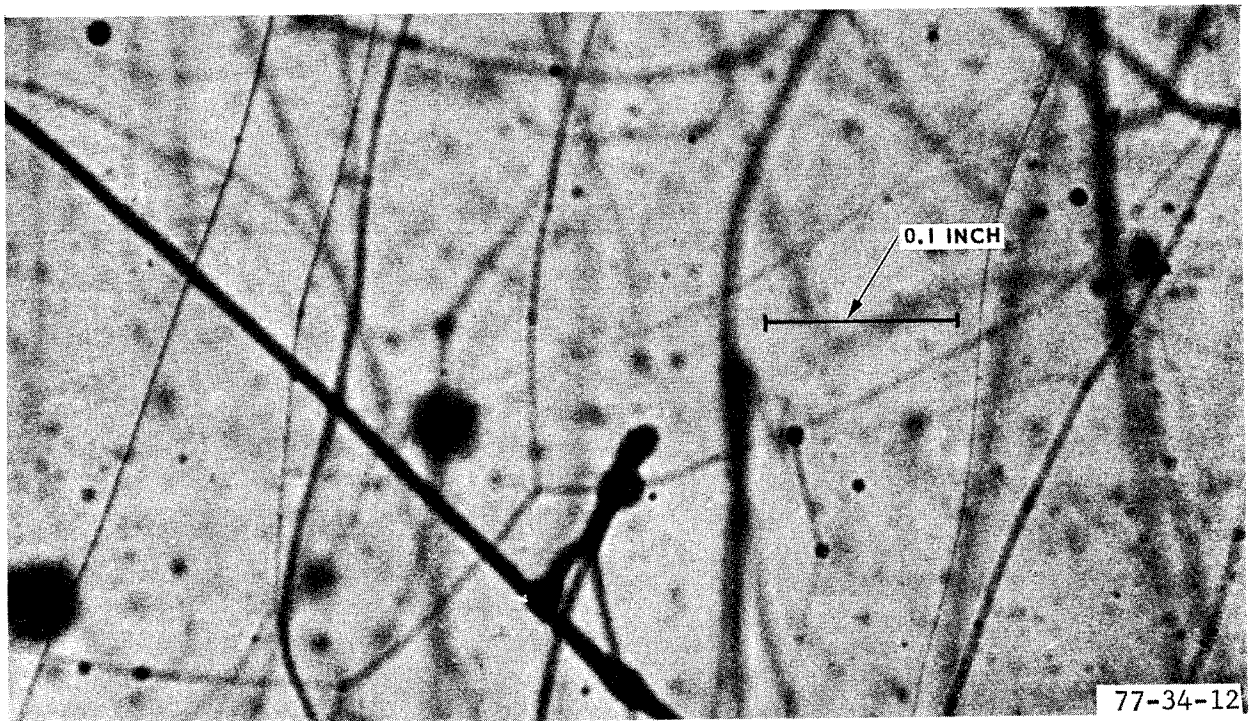


b. 285 mph

FIGURE 3. NEAT JET A SPRAYS

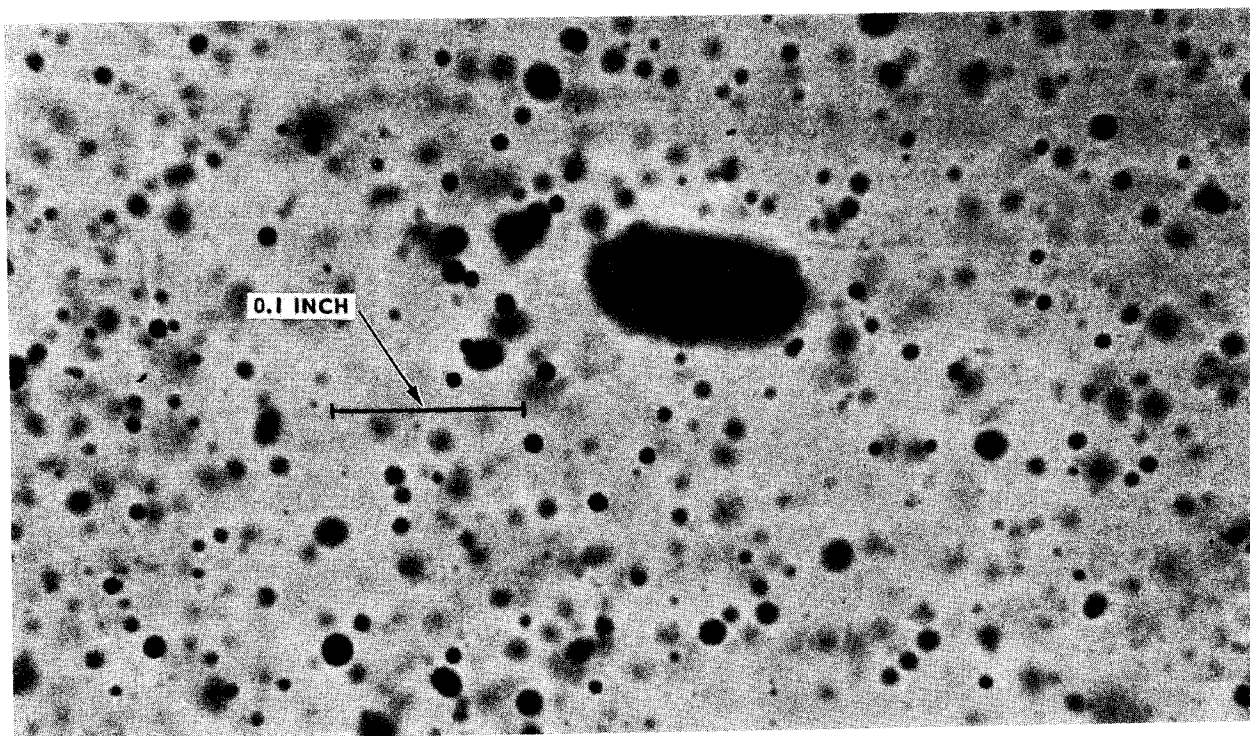


a. 200 mph

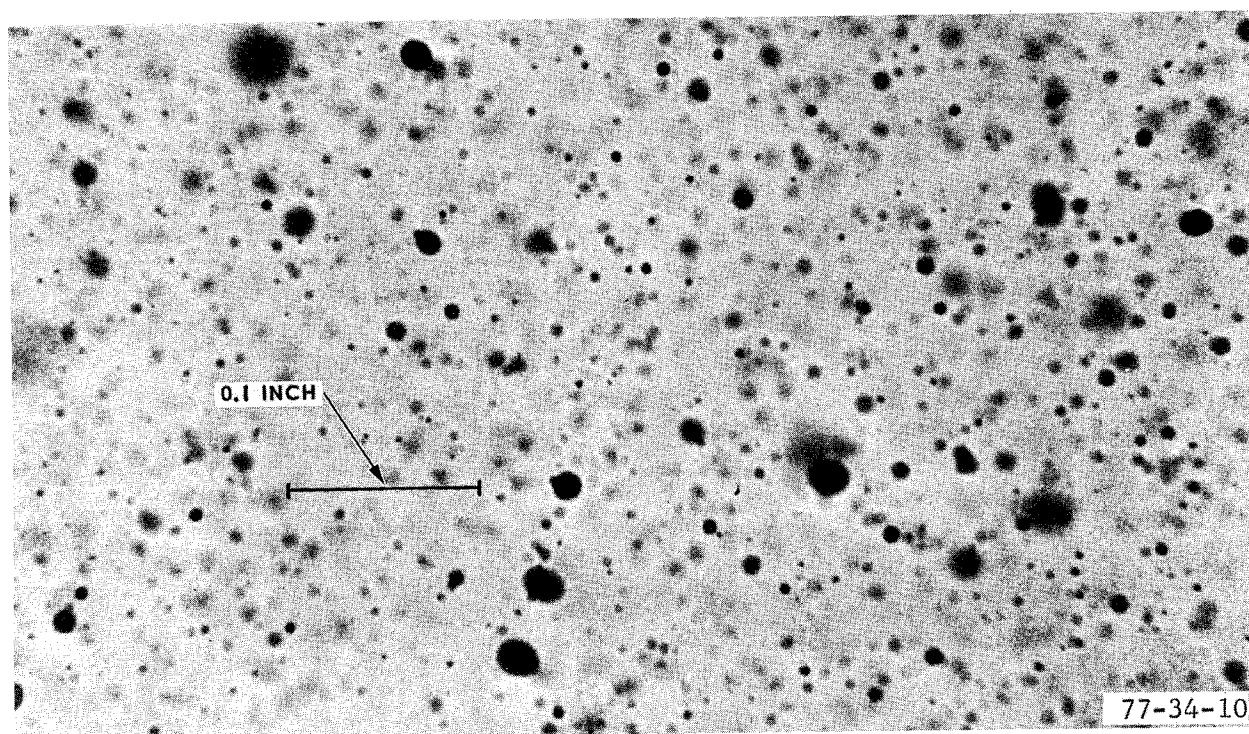


b. 285 mph

FIGURE 4. AM-1 SPRAYS

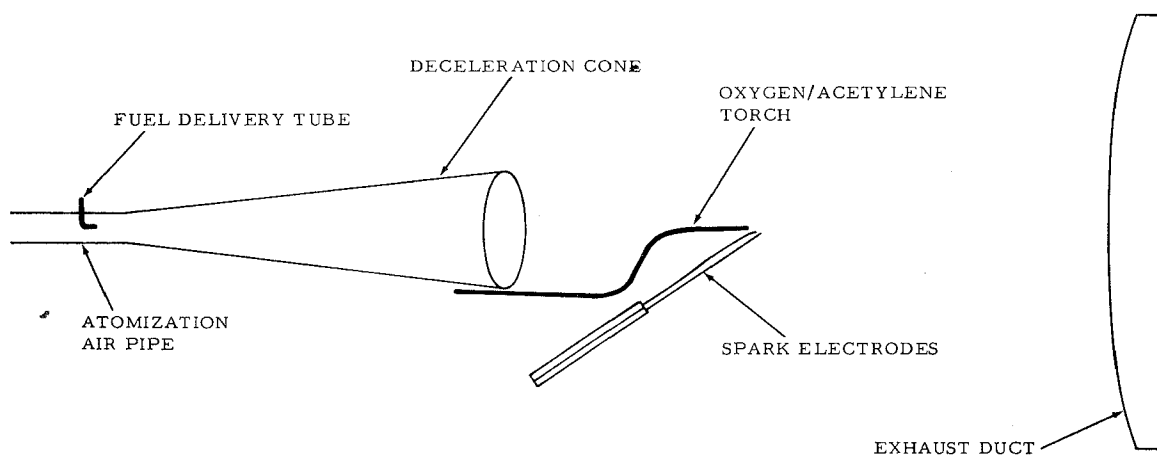


a. 200 mph



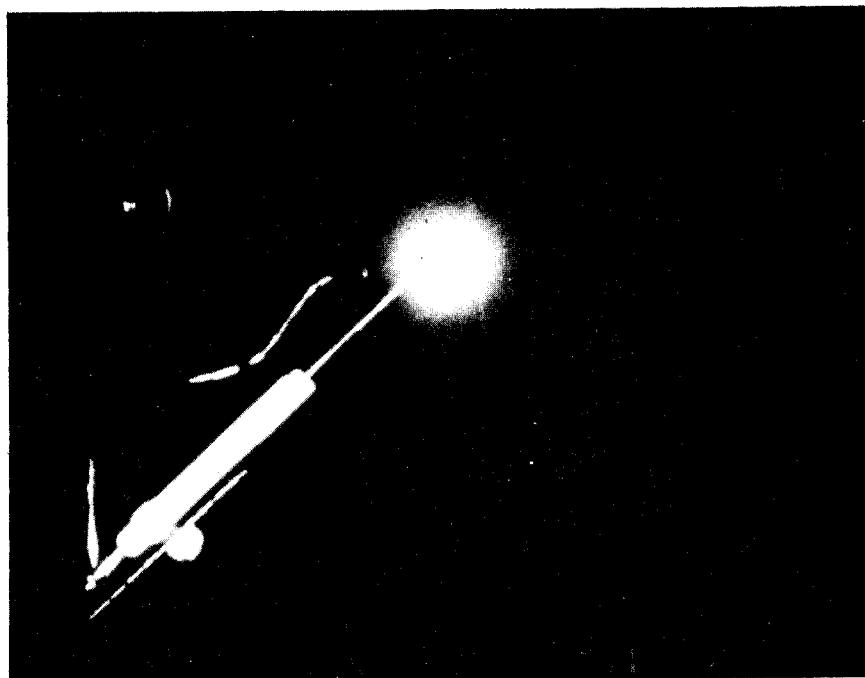
b. 285 mph

FIGURE 5. FM-9 SPRAYS



A. TEST SECTION SCHEMATIC

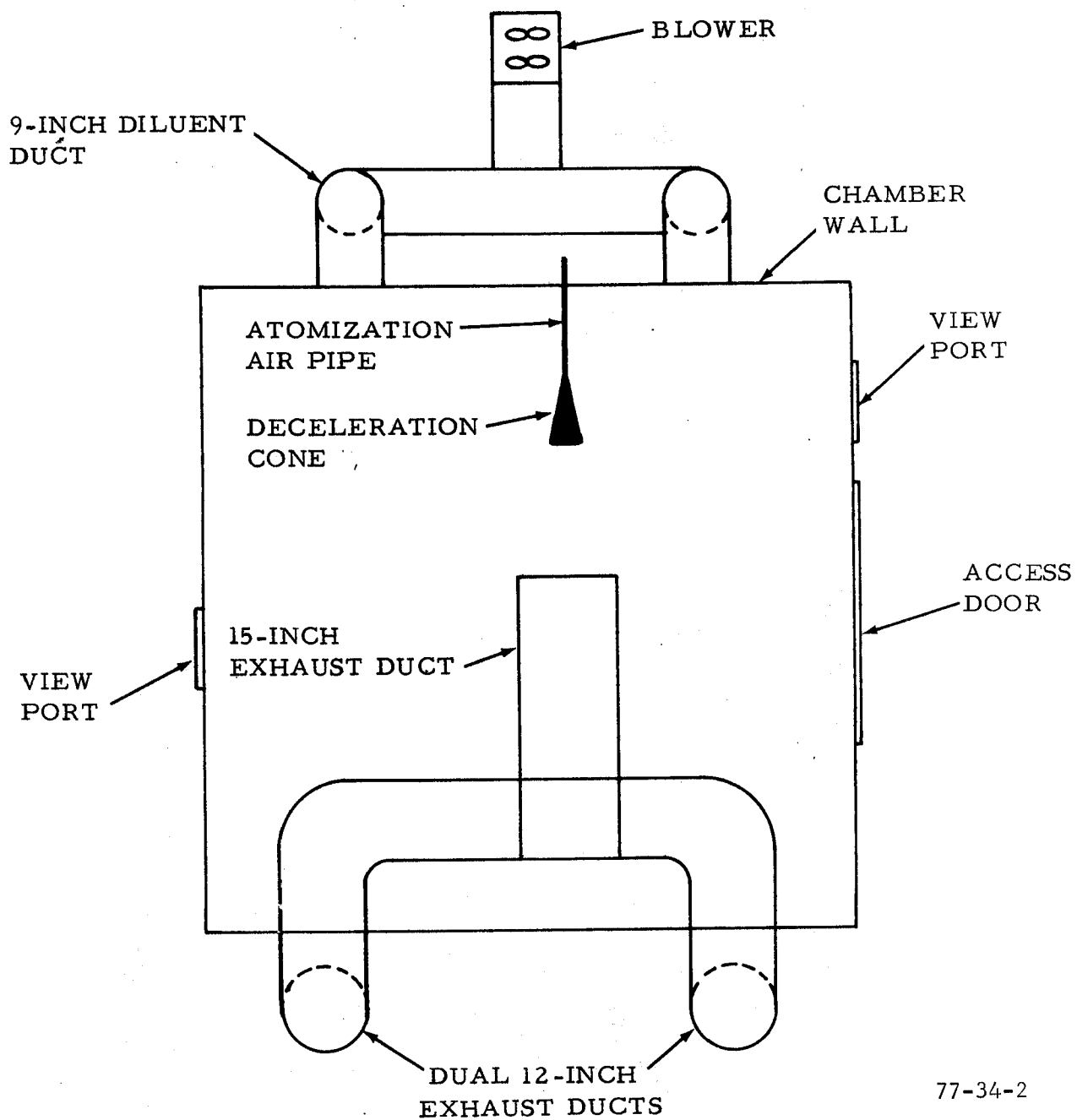
77-34-13a



B. IGNITED TORCH

77-34-13b

FIGURE 6. TEST SECTION SCHEMATIC



77-34-2

FIGURE 7. CHAMBER SCHEMATIC

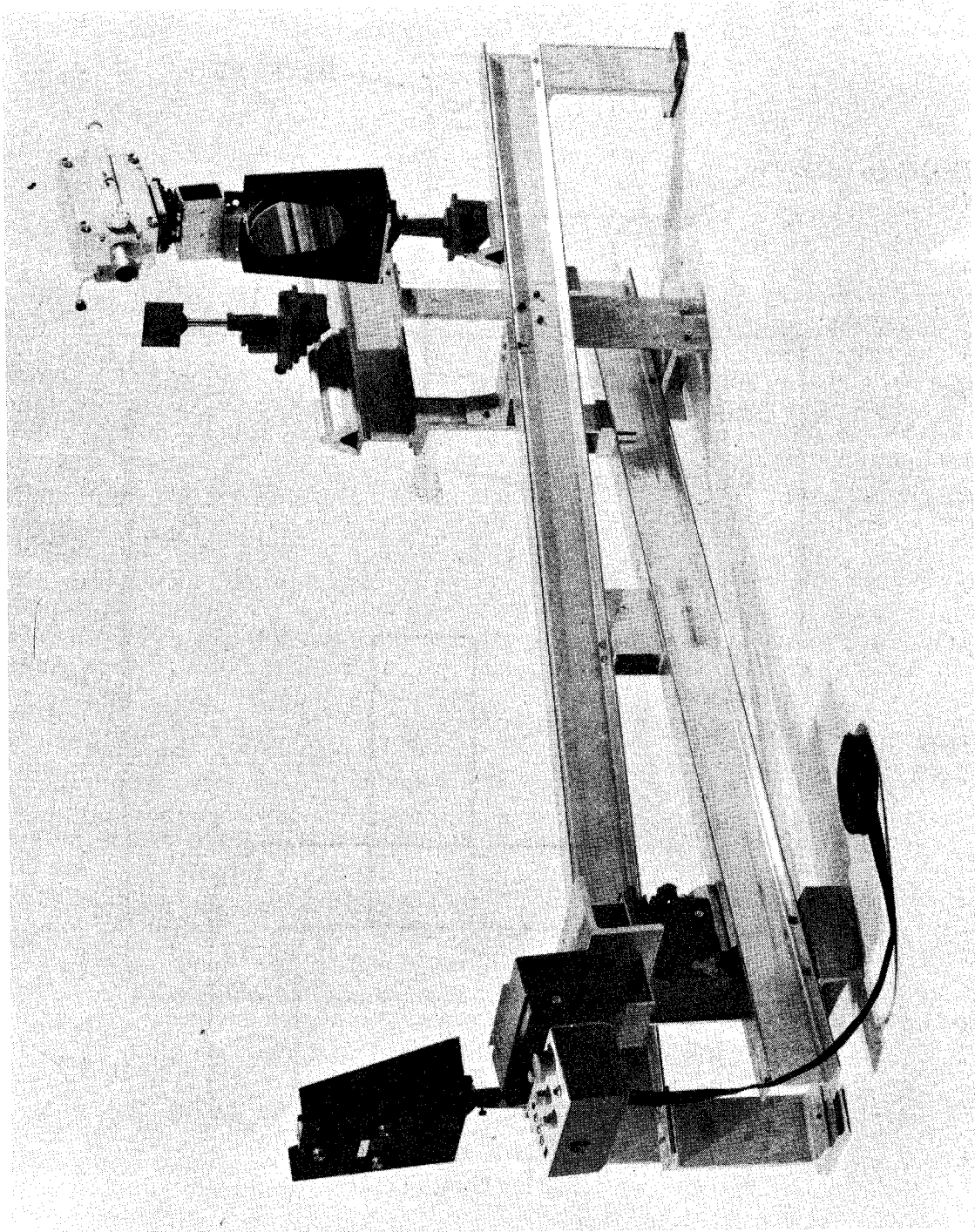
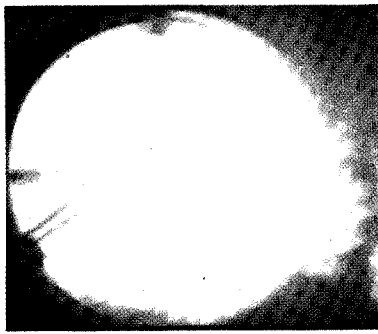
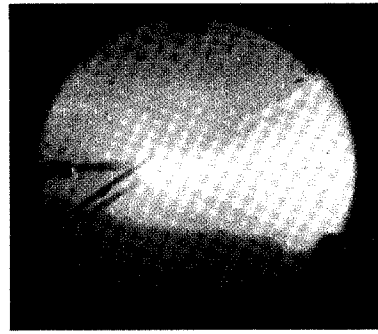


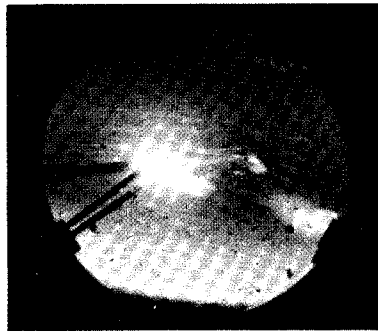
FIGURE 8. SCHLIEREN SYSTEM



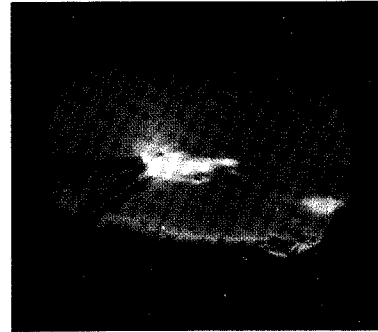
A



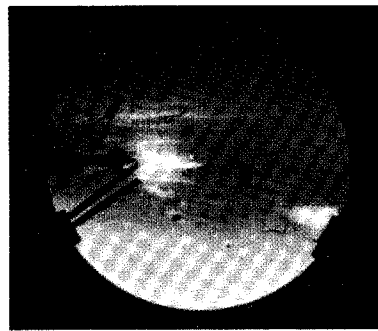
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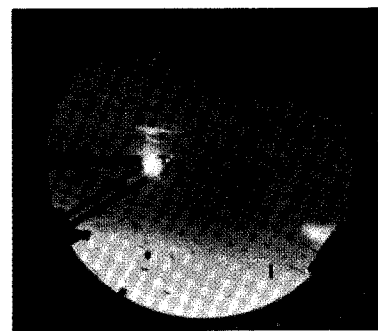
B



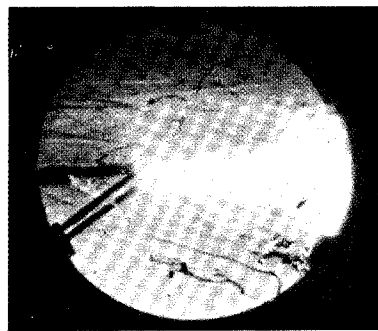
F



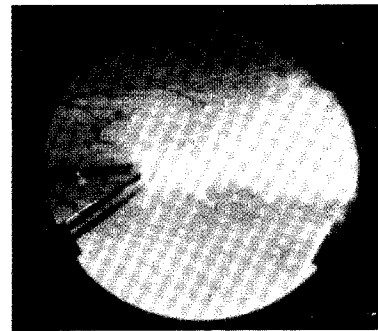
C



G



D



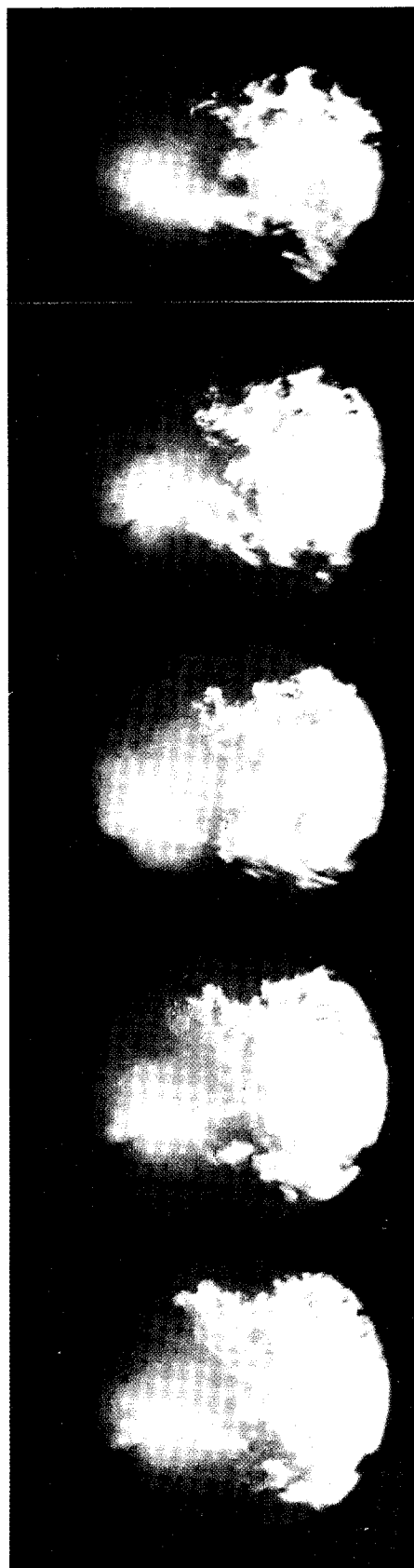
H

78-66-LR-9

FIGURE 9. MODIFIED FUEL SCHLIEREN FRAMES

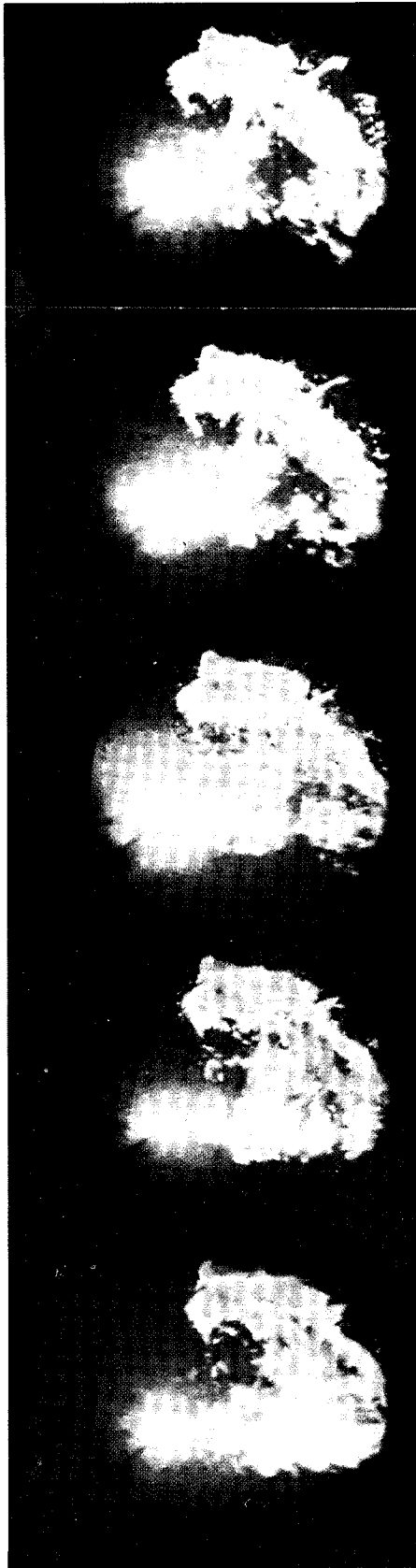


A



B

FIGURE 10. 78-66-LR-10 JET A SCHLIEREN FRAMES



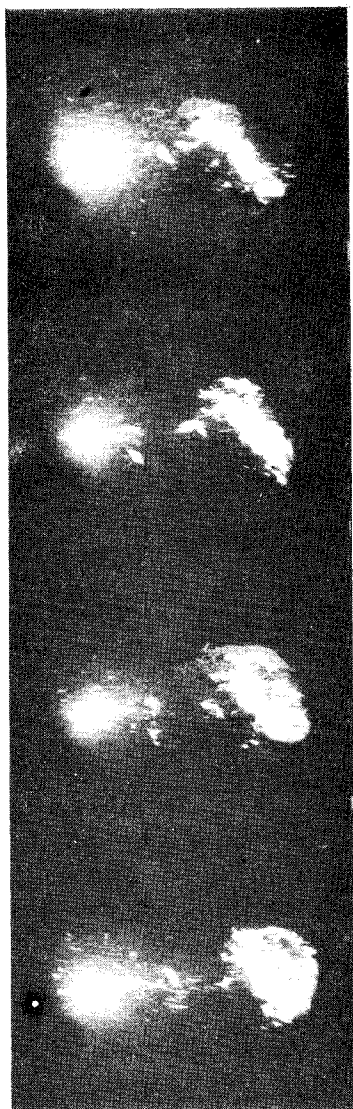
A



B

78-66-LR-11

FIGURE 11. JET A SCHLIEREN FRAMES AT INTERMEDIATE AIR FLOWS



A



B



C

78-66-LR-12

FIGURE 12. FM-9 SCHLIEREN FRAMES